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# HISTORY OF THE GREAT LAKES.

Spencer.

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# CHAPTER I.

## The Evidence of Continental Elevation during the Formation of the Valleys of the Great Lakes.*

IF, in the growth of the American continent, the moulding of the land features had not largely depended upon its projection above the sea, favoring or retarding the action of rains and rivers in sculpturing its surface, there would be little interest as to what was its relative height, before the commencement of the Pleistocene period. But we find valleys vastly greater than the meteoric agents could have produced under existing conditions Thus, there are not only deep cañons, but also vast depressions, descending to levels far below the sea, which are now filled with the earlier drift accumulations, or form channels submerged beneath ocean waves, or constitute basins occupied by lakes. Hence, in the study of the drift itself, in the investigation of the lake history, or in the research upon the growth of modern rivers, we necessarily inquire what was the altitude of the continent that would permit of the mouldings and channelings of the original rock surfaces.

Following the period of high continental elevation, the geologist sees in the valleys and old channels, still below the level of the sea, and in the high level beaches, extensive submergence, succeeded by a re-elevation, but not to the original height, when the continent was being chiseled out by the ancient rivers. That this re-elevation is still going on is shown by the northward tilting of the comparatively recent marine accumulations along the St. Lawrence valley and Gulf coast, and the raised beaches in the lake region, as well as by the shoaling of the waters of Hudson's Bay during the present period of observation.

As general statements do not satisfy investigation, it becomes necessary to search for definite measurements of the former height of the continent among the archives of the geological past. Let us first seek for the testimony recorded by the Mississippi river.

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*Reprinted from BULL. GEOL. SOC. AM. vol. I, pp. 65-70, 1889, where the text appears under title of "THE HIGH CONTINENTAL ELEVATION PRECEDING THE PLEISTOCENE PERIOD."

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While these records of the Mississippi, which have been only partially deciphered, do not furnish all of the desired information, yet as far as they go they are invaluable.

Passing from the buried channel of the Mississippi to its continuation, now submerged beneath the waves of the Gulf of Mexico, we find evidence indicating such a stupendous continental elevation as to be almost incredible, were it not supported by collateral evidence, upon both the Pacific and Atlantic coasts. The soundings off the coast of the delta of the Mississippi indicate the outer margin of the continental plateau as submerged to a depth of 3,600 feet, indented by an embayment of another hundred fathoms in depth, at the head of which there is a valley a few miles wide, bounded by a plateau from 900 to 1,200 feet above its floor. This valley is now submerged to a depth of 3,000 feet, and is the representative of the channel of the ancient Mississippi river, towards which it heads.*

On the Pacific coast, in the region of Cape Mendocino, Prof. George Davidson has identified three valleys now submerged to from 2,400 to 3,120 feet, and several of inferior depth. These measurements are those of the valleys where they break through the marginal plateaus of the continent, at about six miles from the present shore, where it is submerged to the depth of 100 fathoms.†

The soundings along the Atlantic coast reveal similar deep fjords. The long-since known extension of the Hudson river, beneath the Atlantic waters, is traceable to the margin of the continental plateau, acquiring a depth of 2,844 feet, in front of which the soundings show a bar, covered with mud, which, however, is now submerged to the depth of only 1,230 feet. The unpublished soundings off the mouth of the Delaware river bring to light another valley, the floor of which is now covered by ocean waves to nearly 1,200 feet — its continuation seaward not having been ascertained. (Lindenkohl.)‡

Were the continent elevated only 600 feet, the Gulf of Maine would be replaced by a terrestrial plain, in some places 200 miles wide, but traversed by rivers, one of which, towards its mouth, would be 2,064 feet deep — that is to say, the bottom of the fjord is now submerged 2,664 feet. Even this great depth may not be its maximum, for along the line between the opposite banks, at the mouth, now beneath 100 fathoms of water (which is approximately the depth to which the real margin of the continent is submerged), we find that the sea is nearly

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*J. W. Spencer, "The Mississippi River During the Great River Age," New Haven, 1884, p. 2.

†Geo. Davidson, Bull. Cal. Acad. Sc., vol. II, 1887, p. 265.

‡Appendix 13, Rep. U. S. Coast and Geodetic Survey for 1887 (1889), pp. 270-73.

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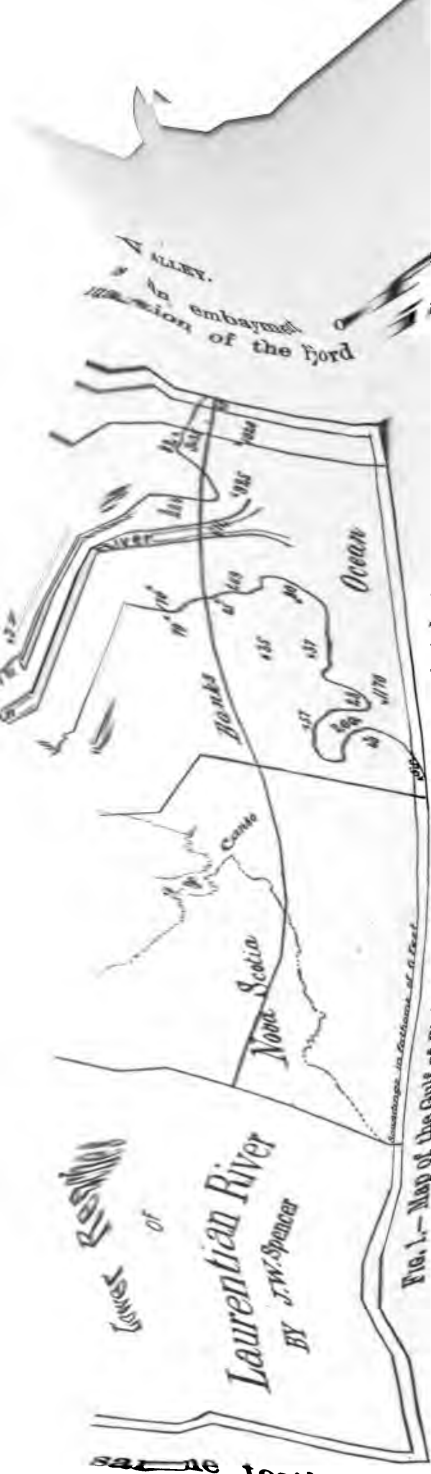
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Soundings in fathoms of 6 feet
Lower Region of Laurentian River
BY J.W. Spencer

Fig. 1.—Map of the Gulf of St. Lawrence, Showing the course of an ancient river.

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a fjord whose waters reach a depth of 840 feet. In the St. Lawrence river, a little below the mouth of the Saguenay, there is a channel 1,134 feet below the surface. This increases in depth in passing seaward. In the region of the centre of the modern gulf, the floor of the old channel is now submerged 1,878 feet, and the adjacent valley 1,230 feet; thus showing the cañon as being over 600 feet deeper. As at the mouth of the channel through the Gulf of Maine, so at the mouth of that of the St. Lawrence, there is a deep chasm; for inclosed between the banks, 100 fathoms below the surface, there is now the depth of 3,666 feet, with water 2,000 feet deeper just seaward of it. Although this ancient valley is over 60 miles wide at its mouth and was a narrow channel, yet it is not as broad as some portions of the modern so-called river. The breadth of the submerged valley throughout its windings for a length of 800 miles or more, is remarkably regular, only gradually increasing its magnitude in passing seaward. Other and smaller channels are visible in the soundings: thus, south of the Straits of Canso, between Nova Scotia and Cape Breton island, there is one 1,200 feet deep, according to the British admiralty charts, while adjacent soundings show less than 600 feet of water.

Hudson's Bay rarely exceeds a depth of 600 feet, yet at the outlet the channel is 1,200 feet deep. This depth increases in passing down the straits, where the scanty soundings show 2,040 feet before reaching the mouth. Here, in Hudson's Straits, the old valley is a chasm across a mountain system, whose peaks, upon the southern side rise to 6,000 feet above tide. The cañon of the St. Lawrence also crosses the trend of two mountain systems, but these are of no great height. The same is true for any of the other submarine valleys described.

The record of a former high continental elevation is again inscribed in the depths of the Great Lakes — Ontario reaching to 491 feet below ocean level, Superior to nearly as much, Michigan to 300, and Huron to 150 feet. The lake basins are merely closed up portions of the ancient St. Lawrence valley and its tributaries. Their distance from the sea would necessitate not merely a general elevation of the continent, but also a greater amount of elevation towards the head-waters of the system, as has been shown with regard to the excavation of the upper portion of the ancient Mississippi cañon. The lake basins are all excavated out of Paleozoic rocks, except a part of that of Lake Superior.

The soundings do not afford all the information that we desire, yet they demonstrate the presence of submarine valleys reaching upon all our coasts to depths of 3,000 feet or more. Again, the soundings

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were pecipitated in great cascades. In the fjords of Norway, merging into rapidly contracting valleys, or headed by great vertical walls, hundreds of feet in height, having the structure named *cirques*, may be seen to-day the counterpart of the coast of the American continent, when its marginal plateaus stood 3,000 feet higher than at present; yet Norway stood once much higher than now, but was afterwards submerged, from which depression it has only recently been re-elevated so that its plateaus, close upon the sea, rise to a height of three or four thousand feet, and its mountains still higher. The old hydrography is more or less distorted by warpings of the earth's crust, which, however, do not obscure the valleys, although rendering the features somewhat more complex. The amount of distortion has yet to be determined.

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* From the Q ARTERLY
Vol. XLVI, pp. 3-533.

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London for November, 1890,
ors D. F. H. Wilkins, W. W.

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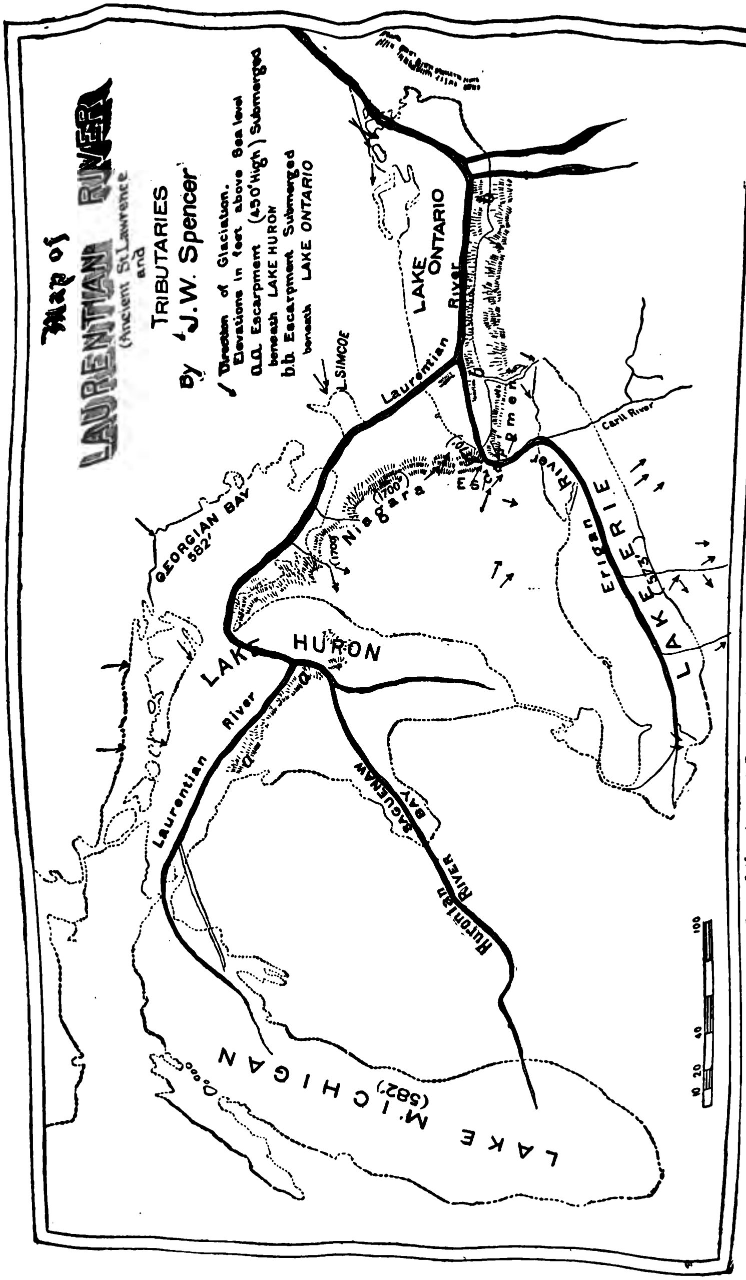

Fig. 2.—Map of the Ancient Laurentian River and its Tributaries.

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Similar channels, buried to depths below the floor of the eastern end of Lake Erie, near Buffalo, have been described by Dr. Julius Pohlmann.[*] The borings into many others in the region of the western end of the lake have been recorded by Prof. T. Sterry Hunt,[†] and prove the existence of similar buried channels.

The original recognition[‡] of the valley-like character of the basins of Ontario and Erie was based upon the above-mentioned characters, and upon others now supplemented by a more perfect collection of facts; but the greatest difficulty in the way of explanation was in the occurrence of the rock-bound outlet of Lake Ontario,—a difficulty which observations have at last dispelled, as will be seen later on.

### *Features of the Huron Basin.*

The southern half of Lake Huron is a plain traversed by valleys and submerged to form only a shallow lake. Northward of this shallow basin, and extending obliquely across the lake for 90 miles, there is a submerged escarpment rising to a height of from 300 to 450 feet, facing northeastward. The deeper part of the lake then trends northward in the direction of Georgian Bay. At one point the extreme depth of the submerged valley reaches 750 feet. The absolute depth of the rock in the deepest channel between Lake Huron proper and Georgian Bay is not known, but soundings show 306 feet; and as there is a deep channel upon the western side of Georgian Bay it becomes highly probable that a deeper and connecting channel is filled with drift, like those known to occur elsewhere, beneath the lakes. From the straits, between the islands, the narrow channel in Georgian Bay, just referred to, extends southeastward and is submerged to a depth of 510 feet. This is at the foot of the Niagara escarpment, which extends, as a strong topographic feature, from the head of Lake Ontario, and, rising in places to 1,700 feet above the sea, into the peninsula between Georgian Bay and Lake Huron proper. The channels at the foot of escarpments, submerged or otherwise, in Lake Huron and Georgian Bay are fragmentary records of the history of the lake-valleys.[‖]

### *Features of Lake Michigan.*

This lake is divided into two basins. The more northern and larger basin has a maximum depth of 864 feet. It is, in part, bounded by

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[*] Paper read before the Amer. Assoc. Advance. Science, 1883.

[†] See Reports Geol. Canada, 1863-66.

[‡] See "Discovery of the Preglacial Outlet of Lake Erie," etc.

[‖] See U. S. Lake-Survey Chart of Lake Huron, and the Canadian Chart of Georgian Bay.

the level of the bay. Lake Simcoe is 140 feet above Georgian Bay, but upon its northern side, at Barrie, a well has been sunk in the Drift, without penetrating it, to a depth of 280 feet below its surface. Thirty miles further inland, south of Lake Simcoe, at Newmarket, a well was in the process of being bored. It had reached a level below Georgian Bay and was yet in drift deposits when visited. In another well several miles to the westward, near the side of the ancient buried valley at Beeton, rock was reached at 50 feet below the surface of Georgian Bay.

Between Newmarket and Richmond Hill there are several deep wells on the heavy drift ridges which cross the country. But at Richmond Hill, at a height of 217 feet above Georgian Bay, there is a well 400 feet deep without penetrating the drift. This proves the thickness of the Drift of the higher ridges crossing the old valley north of the well to be not less than 700 feet in the old channel. Southward of Richmond Hill the country falls away in a series of more or less rolling steppes to Lake Ontario, but these plains show the absence of rock along deeply-cut valleys to far below the level of the upper lakes. Upon the western side of this chain of borings, but a few miles distant, there is the Niagara escarpment. Upon the eastern side of Lake Simcoe the country is covered with flat limestones, rising to 150 feet above that lake. From the known absence of rocks along the line of borings and stream excavations, between a high mountainous escarpment upon one side and a rocky floor upon the other, and from these borings reaching to 200 feet or more below the upper lakes, without penetrating the drift but stopping in quicksand, there has been discovered the existence of the only channel of antiquity which could now draw off the waters of the upper lakes, if the drift were removed. Although none of the borings have reached the original rocky floor, yet the depth of the buried valley is suggested by the channel close upon the northern side of Lake Ontario, now submerged to 474 feet, which is deep enough to drain the last drop of water out of Lake Huron.

We have now found the ancient Laurentian channel from Lake Michigan through Lake Huron and Georgian Bay, and thence buried beneath drift deposits until it is again recognizable throughout nearly the whole length of Lake Ontario, being joined at the western portion by an ancient outlet of the Erie valley (the ancient *Erigan* River). But the relative maximum depression of the channels, as far as explored, is disturbed by terrestrial warpings, to be described hereafter.

Across the southern part of the peninsula of Michigan, between hills rising upon either side to heights of sometimes 800 or 1,000

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### *The Former High Continental Elevation of North America.*

If the lakes and valleys originated from atmospheric and river erosion, then the continent stood at much greater elevation than at present, as shown by the depth of the lakes themselves. But there is much collateral evidence that in the later Tertiary days, probably during the Pliocene, the continent was very high. This is shown by the submerged valleys of the St. Lawrence Gulf, of the Gulf of Maine, off New York, at the mouth of the Mississippi river, upon the Pacific coast, and in Hudson Strait. These indicate that eastern America stood for long ages at between 1,200 and 1,800 feet above its present altitude; and the whole continent in more recent times, but for a brief period, at upwards of 3,000 feet.* Hence the former continental elevation was sufficient to satisfy all demands for the erosions of the lake-valleys; but the rocky barriers still demand explanation, both on account of the present obstructions not having impeded the erosion of the valleys, and on account of their subsequent closing the valleys, in part, into lake basins — the necessary observations for the explanation having long eluded investigation.

### *Deformation of Raised Shores and Beaches.*

At the close of the episode of the newest till, the region of the Great Lakes was submerged to a depth of at least 1,700 feet, as is recorded in the beaches which overlie the till. These high beaches only remain as fragments about ancient islands; but if we descend to beaches of lower levels we find them well developed and containing all the necessary evidence for explaining the rock-barriers at the outlets of the lakes. Gen. G. K. Warren, Corps of Engineers, U. S. A. was the first to suggest the closing of the lakes by warpings of the earth's crust.† Portions of the high-level beaches about the lakes have long been noted. But it was Mr. G. K. Gilbert who first connected the beaches upon the southern and eastern sides of Lake Ontario, and measured their great rise towards the northeast; but, as he did not apply his discovery to the explanations of the lake basins, it was first applied by the present writer.‡ The results of Mr. Gilbert's investigation of beaches in New York and Ohio, and of the writer's researches in Canada, Michigan, New York, and elsewhere, are sufficient to form a chapter by themselves, and are still only in part published, but I will

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* "High Continental Elevation preceding the Pleistocene Period," by J. W. Spencer, Bull. Geol. Soc. Am. vol. 1, 1889; and Geo. Mag., May, 1890.

† Appendix 13, Report of Chief of Engineers, U. S. A., 1875.

‡ See "Notes on the Warping of the Earth's Crust in its Relations to the Origin of the Basins of the Great Lakes," Amer. Nat. Feb., 1887, pp. 168–71.

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more elevated beaches in the region of Lake Huron record a still greater change of level.

At the outlet of Lake Erie, Mr. Gilbert and myself find a differential uplift of about two feet per mile, and this is sufficient to account for any rock basin to the recently formed basin of Lake Erie.

The warping affecting the Michigan Basin has been that towards the north and east; and even in the burried channels south of Lake Michigan there is no evidence of an ancient drainage to the south, as their beds were too high compared with those of the northern, although the latter have been elevated recently by warping.

### *Conclusions from the Observations.*

The valleys of the great lakes here studied are the result of the erosion of the land-surfaces by the ancient St. Lawrence (named by the writer *Laurentian*) river and its tributaries, during a long period of continental elevation, until the streams had reached their base-planes of erosion, and the meteoric agents had broadened the valleys. This condition was at the maximum just before the Pleistocene period.

The closing of portions of the old Laurentian valley into water basins occurred during and particularly at the close of the Pleistocene period, owing, in part, to drift filling some portions of the original valley, but more especially to terrestrial warpings of the earth's crust, which, to a sufficient degree, are measureable.

### DISCUSSION.*

The Chairman noted that there were one or two Fellows who had a local knowledge of the area, but the question of the origin of lake-basins in general was raised in the paper.

Dr. Hinde did not think that Dr. Spencer's explanation of the origin of the American lake basins was the true one. The submerged deep channels of the alleged ancient rivers, to which the erosion was said to be due, were traced towards the east end of Lake Ontario, where they ceased; and their discontinuity through the barrier formed by the hard gneissoid region of the Thousand Isles was attributed to differential elevation, or so-called earth-warping. This assumed warping where barriers existed could always be brought in to account for them. He (the speaker) asked where the beaches existed near Kingston, at the east end of Lake Ontario, on the difference of level of which the supposed warping was based. From his own observations on the region, he doubted the existence of the alleged buried channel between Lakes Huron and Ontario, and he did not think that the acknowledged

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* Before the Geological Society of London.

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# CHAPTER III.

## Ancient Shores, Boulder Pavements and High-Level Gravel Deposits in the Region of the Great Lakes.*

### I. CHARACTERISTICS OF ANCIENT SHORE-LINES IN THE REGION OF THE GREAT LAKES.

THE land features throughout the lake region drained by the St. Lawrence river owe their formation largely to the action of waves sculpturing rocky or modeling earthy shores. That the waves have not always been confined to the margins of the modern lakes is seen in the sea-cliffs and beaches, from which the waters have long since receded. These features, still remaining, are sometimes in the form of bold relief, and sometimes in the form of narrow sand or gravel ridges, delicately traced over a flat country. In some places these ridges approach near to the lakes; in other localities they are miles away, and at varying altitudes up to hundreds of feet above their present waters.

The raised shore-lines are no longer water levels, for terrestrial movements, since the lakes have receded from them, have commonly lifted them up to unequal altitudes. Whilst some of these old shores represent former lake boundaries, there seems to be little reason to doubt that the higher sea-cliffs and beaches formed the coast of brackish water inlets or arms of the sea.

Besides the deformation arising from the unequal terrestrial movements, the shores have been in many places defaced by the action of rains, rills, rivers and landslides, until their broken continuity renders them somewhat difficult to follow over long distances. The object of this chapter is to describe the characters of the old raised and deformed water-margins, by which they can be identified. The ancient coast-lines differ in no respect from the modern, but they are often easier to follow, as there are no waters to restrict one's footsteps. Were the lakes to be suddenly drained, but a few years would elapse before the deserted margins would be as difficult to mark out with precision as any of those from which the waters have long since receded.

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* Reprinted from BULL. GEOL. SOC., AM. Vol. I., pp. 71-86, 1889.

extend for a distance of nine miles. Here the cliffs are being eroded. The waves are not forming a permanent beach, but the currents are drifting the materials several miles to the west to build up the barrier-beach in front of Toronto harbor.

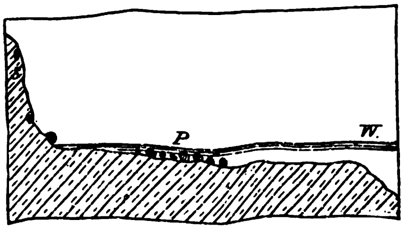

Fig. 5.—*Section showing the Floor of a Cut Terrace without Beach but with Boulder Pavement.*

*P*= Boulder pavement. *W*= Old water-level.

In the formation of beaches there is a tendency to straighten crooked coast-lines by the construction of bars in front of inlets, which are thus converted into bays or lagoons. Burlington bay, at the western end of Lake Ontario, is an illustration. Here, a narrow beach (*b*, fig. 6) cuts off a bay five miles long, whose depth is considerable, reaching to 78 feet. This is particularly a well-chosen example, for at the head of the bay there is a spit — named Burlington heights (*h*, fig. 6), rising to 108–116 feet above the lake — cutting off an older bay, now represented by the Dundas marsh. This spit, when the waters were at its level, formed a portion of an ancient shore (to be described in a future chapter) in the same manner as Burlington beach forms a portion of the modern lake-shore.

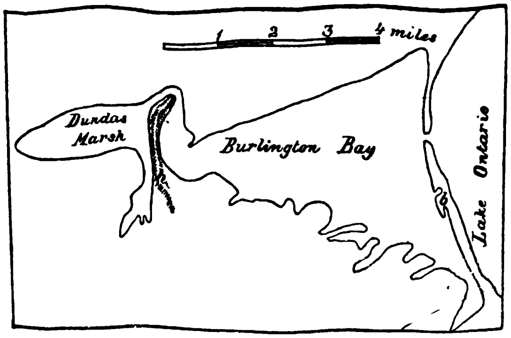

Fig. 6.—*Map of the Western End of Lake Ontario.*

*b*=Burlington beach, separating Burlington bay from the Lake. *h*=Burlington heights, an ancient beach 108–116 feet high, separating Dundas marsh from Burlington bay.

In places, where the waves break upon the more exposed coast, the beaches are apt to be piled up a few feet higher than their mean level. The opposite result is seen where the ridges are fashioned as spits and

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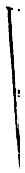

Fig. 7.—*Section showin*

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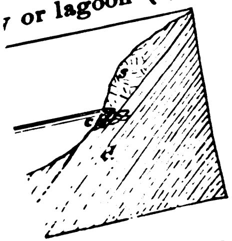

...ment of Old Beach partly concealed by a ... ach. d = Drift. s = Landslide. w = Old

lake coast is composed of drift
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Another structure, when present, is very characteristic of any portions of the ancient shores, or, indeed, is occasionally seen in front of the modern beaches. This is a pavement of boulders (derived from adjacent shores of boulder clay), occupying a given zone (P, figs. 4 and 5). This zone is in front of and a few feet lower than the level of the true beach; the boulders having been left just below the water-level as the waves made encroachments upon the coast. Again, the boulders have been more or less pushed up to this line by the waves forcing up the coast-line to which these boulders have been frozen. When these deposits occur adjacent to the modern beach, they may be seen rising out of the water, but they are also found outward in the lake to the depth of several feet (figures 9 and 10, p. 38).

In front of an elevated shore, the boulders may be arranged in the form of a zone, even a few hundred yards in width, throughout a vertical range of a few feet, which may be increased to 30 or 40 feet where there is a succession of beachlets close together, marking the gradual recession of the waters. But the upper level of these zones never quite reaches that of the beaches. In traveling along a flat country these pavements of boulders are as certain indications of shore-lines as are any other forms of the beaches (fig. 9, p. 38). Boulders left on the hillsides by the action of rains, washing out the finer materials of the drift clay, are not arranged in belts of symetrical level. The boulder pavements do not usually occur where the adjacent coast is not composed of boulder clay, nor where the beaches are separated from the land by what is now or has been a bay or lagoon. Pavements of boulders are not as commonly seen in front of modern shores as in front of some of those more elevated and ancient.

Turning to the more typical form of the beach structure, as shown in the raised shores, there may be seen sand or gravel ridges, most frequently from 100 to sometimes 500 feet across, rising to 15 or 25 feet above a flat or very gently descending plain, whose surface is most commonly composed of fine clay. Sometimes this descent is so very gradual as to be inconspicuous; at other places the descent is quite sudden. The depression behind the ridge is generally less than that in front of it, and here also the floor may be composed of clay. Where the beach is broad, it is apt to be broken up in a number of ridgelets (c, fig. 3). Indeed, some of the larger and more important beaches mark the recession of the waters by being separated into several ridges, often at considerable distances apart, each a few feet below the preceding,

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they may be narrow with the beaches close together. In many regions, the old shores behind these plains rise and extend across the country as conspicuous ranges of hills. The plains themselves are occasionally eroded by streams, until the whole country is very broken. This is more likely to be the case with terraces of the greater altitudes, and here the more recent surface erosion has often rendered the ancient shore lines hard to follow.

In crossing a series of beaches, the lowest is found to be composed of the finest gravel, or indeed perhaps of sand. In this case it is apt to be more or less heaped into dunes, by the action of winds. The ridges are often divided, but the branches unite again, or else send out spits ending abruptly. Occasionally the materials from which the beaches were formed was stony sand, in place of stony clay. Here, then, the extinct water-margins are difficult to determine, for there is no sharp lithological character, as where a beach crosses a clay plain — to mark the boundary between the sand beach, commonly heaped into hummocks or dunes, and the frontal plain composed of sand.

Many of the upper beaches overlie drift deposits, but those of the lower elevations are more likely to rest upon stratified clay — the sediments carried into the deeper waters whilst the lakes were at higher altitudes. The character of the materials underlying the beaches is commonly the same as that forming the surface of the plain in front of the ridges; but its structure is best shown in sections exposed by the subsequent erosion where streams cutting through the ridges cross the plain. When such streams have been large rivers, as has often been the case, there may be some trouble in tracing the continuity of the beach, especially across a broken country, as a portion of the valley may be older than the beach, which may swing around and skirt the embayment, or form a bar across it. Or again, the beach may be only represented by conical or other shaped sand or gravel hills, which were delta deposits at the mouth of former rivers. Such delta deposits may not rise to the level of the former body of water.

With the varying conditions here set forth, which the shore-lines undergo, the traveler, in coasting around the old lakes, can rarely proceed more than a few miles without meeting obstructions. When the beaches were a considerable distance apart, with perhaps only 50 or 100 feet of difference in their altitudes, there is a liability of getting off one series and upon another. Consequently it is often necessary to resort to accurate leveling, allowing for reasonable variations

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*shore-lines record a great amount of unequal terrestrial movements, yet these movements have also left records in the older sea cliffs.*

## *BOULDER PAVEMENTS AND FRINGES.*

*In many localities of the northern part of our continent, the land surfaces are almost covered with loose boulders, varying from the size of cobble stones to masses commonly three or four feet long. Occasionally the blocks have a length of eight feet, but rarely longer. While some of the boulders are angular blocks of Paleozoic limestones and sandstones of local origin, a great proportion are Archæan rocks, which have been transported from the Canadian highlands north of the great lakes, to distances of sometimes 300 or 400 miles. These crystalline rocks, although so hard and compact, have the angularities invariably removed. Blocks are frequently seen at altitudes of hundreds of feet above their original sources. Throughout the lake region, and the country north of the line of the southern limit of the drift,* which is often fringed with them, the accumulation of boulders is not uniformly distributed. The country enclosed by that line is occupied by sheets and ridges of drift materials, through which the subjacent rocks occasionally protrude. Again, these plains and hills have their surfaces moulded by the action of the waves of vanished seas or shrunken lakes, often fashioning the region into a succession of broad terrace flats and hilly coast lines. It is upon the surfaces of these moulded features that the boulders are found. Whilst there are vast areas where there is not a single stone to be seen, and others where only an occasional block occurs, as dropped down from some meteoric source, there are other localities literally so covered with large boulders as to prevent agricultural pursuits. These boulder accumulations are superficial and do not penetrate the subjacent earths. They occur along certain zones, outside of which they are not fonnd.

The presence of these surface boulder accumulatious has been most commonly explained alike by those who believe in the glacial origin of the drift and those who do not, as having been dropped by melting icebergs at the close of the drift epoch. A few glacialists regard these boulders as having been deposited from glaciers where they now rest. It has also been hinted that they have been left upon the hills, as the finer materials of the boulder drift have been washed away by atmospheric agencies; but it was only since the recent systematic studies of the high-level beaches, compared with modern lake shores, have been made that the natural explanation of boulder pavements and distribution of erratics become possible.

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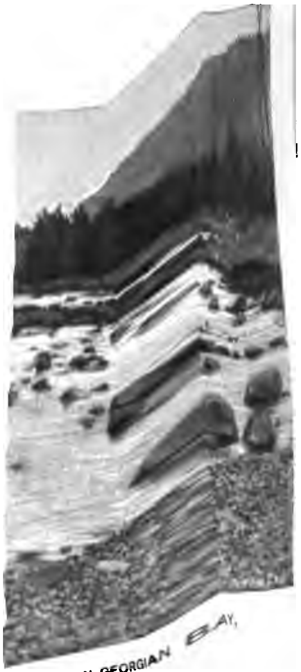
PLATE II.



VEMENT ON GEORGIAN BAY,
ins of Collingwood, Ont.

OF ALGONQUIN BEACH,
n the N. E. Side of Blue Mountains

But the story of the boulder pavements and fringes is not yet complete. Coast-ice has also played an important part in the arrangement of the paving stones. The waves, acting upon the coast-ice wherein boulders have been entangled, cause the stones to be forced up into more regular zones, as to height, than would be affected by the residuary deposition alone, as just described. Blocks of large size can thus be moved, not merely by the heaving action of modern frosts, but by the action of coast-ice itself; for boulders upon the margins of the St. Lawrence river, weighing 70 tons, are known to have been shifted by the spring movements of a winter's ice. Again, the writer has seen upon some of the shores of Shoal lake, in Manitoba, situated in a flat drift-covered country, modern beaches composed of huge boulders, piled up by the waves of the lake acting upon the ice in which the stones were enclosed, as otherwise blocks four or six feet long could not be gathered from the shores of the lake and accumulated into beach ridges, nor could they have been residual pavements as above described, for no high shores of boulder clay occur into which the waves could have made encroachments.

An excellent illustration of the modern formation of boulder pavements and fringes may be seen upon the shores of Georgian bay, between Thornbury and Collingwood, as shown in Plate II, fig. 9. There the lake waves are encroaching upon a shore composed of boulder clay. The larger stones standing out in the water are too heavy to be materially affected by the waves or ice action. Excellent illustrations of boulder zones are found a short distance from this locality, at an elevation of 187 feet above the lake, as shown in Plate II, fig. 10.

Other examples of fringes of boulders high above any modern waters may be seen a few miles beyond the eastern end of Lake Ontario. The same is true upon the northern side of the lake, as for example, back of Trenton and westward; these are parts of and in front of the finer gravels of an old beach, now more than 400 feet above the lake. Westward of Toronto, where the old shores are of Paleozoic rocks, in place of drift, the boulder pavements disappear from the front of the beach.

Upon the steep hillsides, as long the Mahoning valley, near the crossing of the Ohio-Pennsylvania line, there are zones thickly covered with boulders. There we find the records of old water-margins, as well as in the pavements associated with the well marked beaches and shore-cliffs facing the lake basins. The finer materials have been

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fied clays, or included in the drift accumulations themselves, and the ancient shores already described, the following groups of gravels and sands should be noticed, some of which are covered with the stony clay of the upper till:

A. *The gravels and sands which are buried beneath the upper drift deposits.*—These may be divided into (*a*) buried beaches; and (*b*) more or less irregular beds and ridges of gravel and sand, often of earthy texture, having a more or less tumultuous structure, and resting beneath accumulations of the upper till.

B. *Surface accumulations of gravels and sands, forming ridges, mounds and plains.*—These are in the form of (*a*) the so-called osars and kames; (*b*) other ridges and mounds resembling the last, but having a position corresponding to that of beaches, in front of more elevated plains or drift hills, or of the accumulations included in group A *b*; and (*c*) gravel plains

A *a.*—Hitherto, the buried beaches have not been distinguished from other beds of gravel and sand intercalated within the drift formations. As such accumulations, whose structure is the same as that of modern beaches, are only exposed in sections cut through the surface deposits by streams or artificial excavations, all of the knowledge that we can, at present, hope to acquire, is the recognition that there were beaches, now covered by drift, older than those upon the surface of the country. When beds of gravel and sand are met with in borings, it is not always possible to distinguish those which are buried beaches from others which are intercalated with drift deposits. The structure of the buried beaches does not show that tumultuous crumpling, so commonly seen in the next kind of accumulations (A *b*). In some places the gravels are found cemented into conglomerates. Thin layers of stony clay, constituting the upper till, which covers vast areas of the country throughout the lake region, often rest comformably upon the undisturbed surfaces of the buried beaches, that may have a thickness of twenty feet or more. Excellent examples of buried beaches may be seen along the Au Sable river, southeast of Lake Huron, where the overlying drift clay is only four or six feet thick. When the covering is thin, there is a liability of mistaking these older beds for those belonging to the beach epoch proper.

A *b.*—The internal structure of this kind of gravel and sand deposits shows stratification, which may be regular in one place, but the beds soon become tumultuous, that is, the beds become irregular, bent or twisted, and confused. The materials are apt to be somewhat earthy

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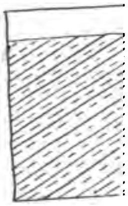

FIG. 11-

*b*—Boulder pavement.
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stony clay, the result of which has been the formation of beach ridges of sand and gravel, separated by plains of silt or clay soil. In many cases, these floors slope so gently as to appear level, and from two to five or six miles may intervene between successive beaches, whose altitudes do not differ by more than 50 or 60 feet. The silt on these plains is that which was washed out into the deeper water, by the assorting action of the waves that were building sand or gravel beaches in front of their coast line, composed of the older stony clay. In such cases, the lithological recognition is striking. Upon surveying, the beaches are all found to rise in altitude toward the north and east, with a slightly increasing divergence between the ridges in the same direction, for the differential uplift has always been greater toward the northeast, than in the opposite direction.

The methods of investigation have been similar to those pursued in the survey of the Iroquois Beach. Boulder pavements are rather more important features of the Algonquin Beach than of the Iroquois. About the head of Georgian Bay the country is sandy. East of Georgian Bay, there is the same kind of broken wilderness as that among the Archæn rocks of the Adirondack Mountains of New York, with more or less stony sand in place of stony clay.

The waves of the lake are encroaching upon the eastern coast of Huron, and consequently modern beach-making is not a characteristic feature, except in proximity to the mouths of some streams or in sheltered places, where terraces or bars are constructed. The encroachments of the lake upon the land have washed away, in many places, the bluffs upon which the Algonquin Beach rests. But a sufficient number

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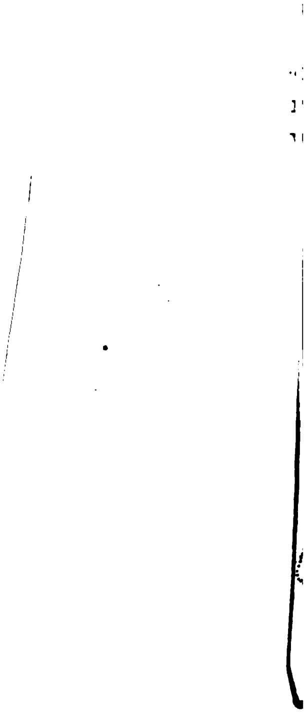
* The name was first printed in Proc. A. A. A. S., p. 199, 1888.



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For comparison with the Algonquin Beach, the positions and the elevations of the two next higher beaches, east of Lake Huron, are given in fig. 14, and the tables of elevations are here added. Of next beach, at or near:

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| Bayfield, east of | 767 | “ |
| Ripley | 813 | “ |
| Walkerton (terrace) | 825 | “ |
| Paisley (terrace) | 860 | “ |
| Burgoyne (east of Southampton) | 876 | “ |
| Rockford, north of | 915 | “ |
| North coast of Lake Simcoe (probably that) on the insular ridge, north of Barrie | 910 | “ |

Of the second beach, above the Algonquin, at or near:

| | | |
|---|---|---|
| Watford | 773 | “ |
| Ailsa Craig | 789 | “ |
| Varna | 845 (+) | “ |
| Walkerton | 944 | “ |
| Chatsworth | 985 | “ |

A still higher beach has been surveyed for many miles, and several fragments of even more elevated shores are now well identified. Some of these upper beaches have been traced over long distances, and have been found resting upon the land north of Lake Erie, and even extending to the high country between Lake Ontario and Georgian Bay.

From the figures recorded in the three tables, it will be found that the mean rate of warping in the Algonquin Beach, from the southern end of the lake to near Southampton, is 1.33 feet per mile; of the next

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depression in which Lake Nipissing lies. The barrier there d to 707 feet above the sea. Beaches and shore lines are known upon the land north of the lakes, and I have seen such upon Ma and Mackinac Island. But they have not been directly connect the more southern beaches. Consequently, all deductions, in th of the lake involving that district, must be somewhat prov From the character of the terrestrial rise increasing towards the is probable that there are no depressions north of Lake Huron than the plain of the Algonquin Beach. This beach (by calc from the mean rate of rise) should be found in the vicinity c Nipissing, at the from 600 to 700 feet above that depression.

Combining the Canadian series of beaches about the upper lak corresponding series on the southern side of the lakes (my su those in Michigan appears in chapter VII), I find that there has differential elevation, since the Algonquin episode, betwee southern end of Lake Michigan and the vicinity of Grand Be Lake Huron, amounting to about 290 feet. Hence, we know t Algonquin plain was down to a level, at least, of less than 3C above the sea. By a triple series of calculations, the Algonquin is found to have had a position somewhat less than 300 feet abo Iroquois plain. The Algonquin water filled the Huron basin to a mile or two of its southern end, where the beach is now subn to about 20 feet, (calculated). Hence, the waters did not flow modern St. Clair River to the south. At the time a considerabl of the southern end of Lake Michigan was laid dry, as the bounding the Algonquin water should now be submerged to 2 below the waters at head of lake. But the northern part Michigan and Huron basins was filled to an elevation far above present surface, as the basins had not yet received that great

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* Geology of Canada, 1863.

seems no
n basin at that eleva-
amounted, since accord-
miles, or a little the
rate of uplift more.
e added that President red
f the lake which repre-
ey belong to an older
earlier Pleistocene
Superior, probably
as that basin is so
iallowed. Indeed,
f Lake Superior is
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its floor. In short the outlet was a broad strait leading
Iroquois Basin, or like the modern connections between Lake
Lake Huron, and Georgian Bay, unless the basin were closed b
and that of ice. The case is not settled so easily as tha
Ontario basin, for we have not yet the instrumentally me
proof that the Algonquin plain was lower than 300 feet above
although it probably was, and against which probability ther
the slightest evidence, for we do not know what was the initial
upward movement. Without applying the objections made
dam closing the Ontario basin during the Iroquois episod
examine some conditions of the Algonquin basin.

The Algonquin plain stood at an elevation of about 300 fee
the sea, when the lower Iroquois Beach commenced its growth.
its waters held up to that altitude by an ice dam, or had they s
to the lower level (which, however, would not have disme
the upper lake) and where they connected with Gulf of Iroqu
strait 300 or 400 feet deep, like the modern outlet of Lake Mi
Up to this time, there had not been any warping to separ
lake basins, for the greater part of the barriers has been uplift
the episodes of the Algonquin and Iroquois Beaches. I hav
that the greater proportion of the differential movement, even
higher beaches about Lake Erie has been since the Iroquois e
In the earlier part of this paper, it has also been shown that
the warping of the beaches, east of Lake Huron, has been si
Algonquin episode. Now these higher beaches are identical wit
south of Lake Erie, whose movement have been compared wit
of the Iroquois Beach. Hence, it is not difficult to understa
the unequal uplift of both the Algonquin and Iroquois plains h
mostly, since the completion of the latter beach. I speak
the differential movements that have deformed the old water

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* "Deformation of the Iroquois Beach," etc. Am. Jour., Sc., vol. x, page 443,

onal uplift

ered, is shown by

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only by a river flowing

her beaches, the question

we must assume then to

ormous altitude, damming

ns of inland seas. Such l

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moving into the St. Law-

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ere is as much evidence of

ere is in Professor Shaler's

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formation‡ which I have

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sh water, the marine con-

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Beach, the waters

Report of U. S. Geological Sur-

Am. Nat., Vol. iv., p. , 1870;

States." (Sidney I. Smith). Rep.

(C. H. Hitchcock). Proc. A. A.

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*Notes upon the Origin and History of the Great Lakes of North America. Pr

A. S., vol. xxxvii., p. 197, 1888.

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s sheet, whose dimensions
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l surveyed for a length of
of the coast line about the
part of the Province of
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I acknowledge with great
Clendenin and Prof W. J.
earches. Respecting the
lake, no other systematic
e years ago, some of our
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had been done, which will
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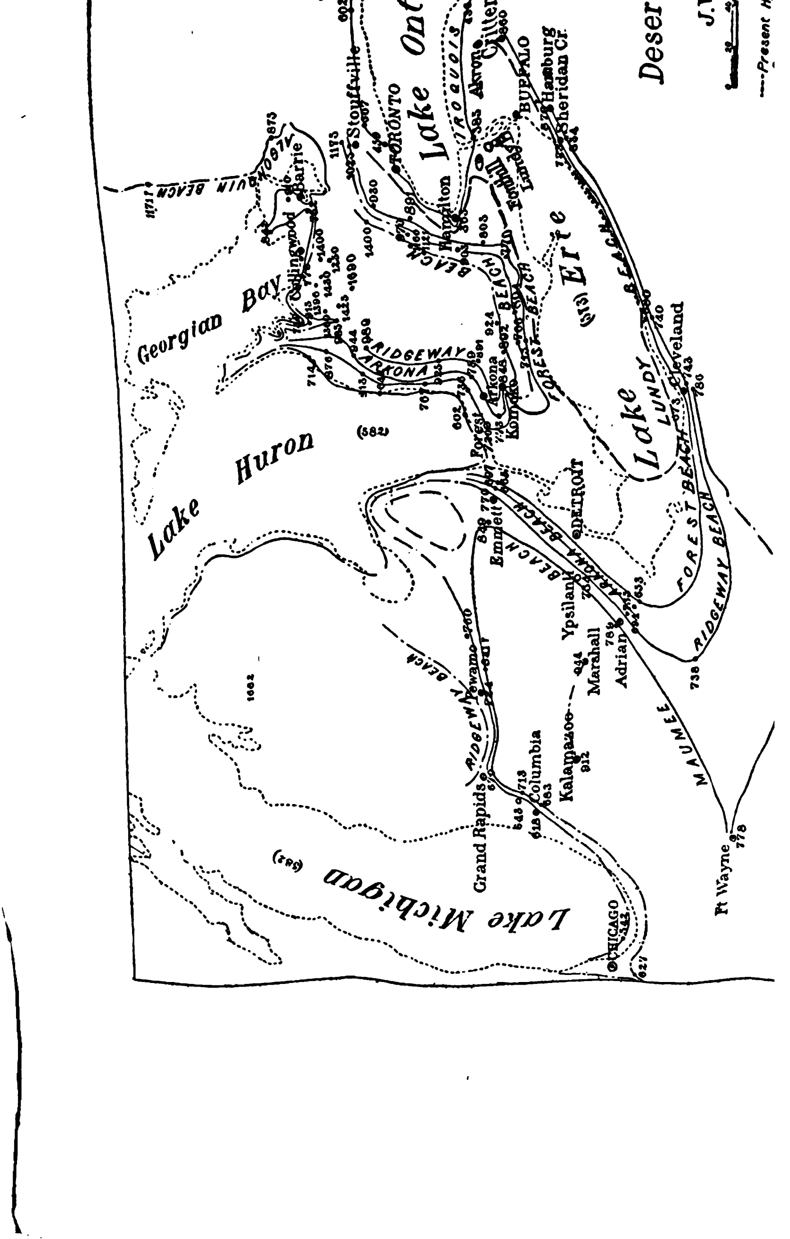

Province of Ontario, is 1.44 feet per mile in a direction of N. 28° E. But northeast of Toronto this warping has increased to three feet per mile as it trends north of east, with the direction of the maximum rise not determined. This warping is in harmony with the deformation of the Iroquois Beach, in the same region, being only slightly in excess, as it should be. No attempt has been made to explore the extreme eastern and northern portions of the Forest Beach, around the island of the Province of Ontario.

*The Arkona Beach.*—This beach is less perfect than the Forest Beach. It is prominent at Arkona, rises to 789 feet east of Ailsa Craig, passes by Varna and Ripley, and near Walkerton has an elevation of 944 feet. At Chatsworth, the spit across the valley at 985 feet, probably belongs to this shore-line. No further explorations have been made in this direction. Southwest of Arkona, the beach has an elevation of 773 feet at Waterford ; 754, on a river terrace near Komoko ; 735 (?) at Taylor ; 776, on the plains at St. Thomas ; 792 at Cornith ; 804 at Delhi. Beyond this point there are shore remains, at 903 feet near Paris; a terrace at Limehouse, at 970, and at Stouffville, a gravel ridge skirting higher land, at 1,175 feet. These latter fragments may be the equivalents of the Arkona Beach. But these last named shore-lines continue the upward succession of deserted water-lines even if not identical with the Arkona Beach. This beach is imperfectly explored, and is more or less interrupted, like other shore-lines, in the lake region as well as those nearer the sea coast, such as on Mt. Desert Island.

*Ridgeway and Higher Beaches.*—Above the Arkona Beach, the next shore-line is here named Ridgeway Beach, (as this a suitable name for its counterpart in Michigan). Its elevation, near the following places, is:

| | Feet above the sea. |
|---|---|
| Komoko | 848 |
| Lucan Junction | 891 |
| Hensall | 925 |
| Lucknow | 989 |

As the object of our surveys was for the more especial investigation of the lower beaches, the explorations were not carried throughout the distribution of the higher beaches. But beaches, spit across valleys, and terraces carved out of the Niagara escarpment were seen in many places at altitudes which would correspond to the continuation of this shore-lines. Back and above this beach, there is a belt of flat plains, corresponding to the frontal plains of still higher deserted coast-lines. Indeed, in the fragments seen, several other still high coast-lines are

ese are here given, and
phical positions that would
y Beach, which has not,
ll the points.

| | Feet above the sea. |
|---|---|
| .......... | *882 |
| .......... | 872 |
| .......... | 862 |
| .. ....... | *924 |
| .......... | 911 |
| .......... | 903 |
| ......... | *1,127 |
| ......... | *1,160 |
| ........ | 1,400 (bar.) |
| ......... | 1,375 (bar.) |
| ........ | 1,200 (bar.) |
| ........ | 1,400 (bar.) |
| ........ | 1,396 |
| ........ | 1,372 |
| ........ | 1,262 |
| ........ | 1,225 |
| ........ | 1,260 (bar.) |
| ) ....... | 1,430 (bar.) |
| ........ | 1,690 |
| ........ | 1,630 |
| ........ | 1,425 (bar.) |
| ........ | 1,400 (bar.) |
| ........ | 1,360 |
| ........ | 1,260 (bar.) |
| ........ | 1,067 |

*lk*, is only 20 feet below
l a small island. From
proof, in the beaches,
as a *long succession* of
the highest lands of the
the highlands north of
*aurentian mountains*—
named structures from
*drift episodes*. Even
rrestrial warping, these
the land to the south

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of the lakes. All of the deserted water-margins are more recent than the drift deposits, and some of them are cut out of the third series of till, which covers ridges and plains of much of the highlands of Ontario. The highlands of the peninsula then rose up as a growing island out of the receding Warren water.

The position and relative heights of the beaches of the two sides of the St. Clair River are seen in the following section, which represents a profile across them along a nearly east and west line. Making allowance for the terrestrial deformation between the beaches themselves, it will be readily seen that there is only a slightly greater amount of rise between members of the series upon the eastern side than upon the western, and this is in harmony with all the observations elsewhere about the lakes. Hence, I have been forced to accept the identity of the two sets on the opposite sides of the St. Clair river, as there are no important intervening shore-markings on the plains between the named ridges, although those upon the western side are more sandy than on the eastern.

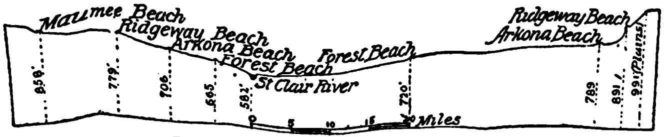

FIG 16.—Section across St. Clair valley.

The Forest beach skirts the plains at the head of Saginaw Bay and passes around the thumb of Michigan.

| | Feet above the sea. |
|---|---|
| Five miles west of Port Huron, duny beach with elevation of, | 665 |
| East of Berville.................................... | 668 |
| Sylvania ......................................... | 663 |
| East of Defiance (Gilbert)............................ | 653 |
| Cleveland ......................................... | 673 (bar.) |
| Madison .......................................... | 680 |
| Sheridan Centre, N. Y. (Gilbert)........................ | 773 |
| Crittenden, N. Y. (Gilbert)........................... | 860 |

The Arkona beach has an elevation of—

| | |
|---|---|
| Goodall, near ...................................... | 697 |
| Denton ........................................... | 694 |
| Blissfield (ridge duny) ............................... | 694 |
| Cleveland ......................................... | 708 |

A record of this shore-line is more meagre than the last. Both of these beaches have been more or less surveyed in Ohio by the late Geological Survey of that State,* and Mr. G. K. Gilbert has measured

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* Geology of Ohio, vol. 1, map, p. 549.

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The Ridgeway B
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long stretches of dry roa
from the first settlement
in places been used for roa

*Elevations on the Rid*

Lake Michigan and Lake Hu
Lake Erie..............
Beach near Chicago (calculate
Near Columbia, Mich.... .....
Allegan (terrace) in valley......
Grand Rapids................
Pewamo .....................
Chapin.......................
East of Emmett................
Near Berville...... ...............
East of Ypsilanti..................
West of Lenawee Junction.........
Defiance, Ohio... .................
Cleveland.........................
Madison...........................
Sheridan Centre, N. Y.................
Hamburgh, N. Y......................

Throughout the windings, this coast line h
or nine hundred miles. The highest beach s
42 feet above the lake, and this probably be
noted here [illegible] after, and from it the position of t
calculate [illegible] The country southeast of Lake M
and dun [illegible], and thus it is more difficult to recog
margin [illegible] than farther east where the beaches are na
clay p [illegible] the beaches a
a stra [illegible] ins. From Grand Rapids to Pewamo the
occup [illegible] ght between high lands on both sides. Th
those [illegible] ed by the Grand River, between the head
draining into Saginaw Bay, the divide d

of 100 feet above the lakes, although the land rises many hundred feet on both sides. Indeed, from even west of Pewamo the low embayment widens and forms the broad flat plains at the head of Saginaw Bay. But these plains, for half their length, are drained to the west by the Grand River, although they were formerly the floor of the lately enlarged Saginaw Bay. Hence, the topography shows the reversal of the drainage, by a slight uplift towards the east and north, which in the region of Pewamo amounts to about a foot per mile. This rise continues to Chapin, whence the beach rises towards the northeast and passes around the thumb of Michigan, and descends to about a mile east of Emmett. From the crossing of the beach, east of Ypsilanti, to Lenawee, there is no terrestrial warping as shown by instrumental measurements. The occurrence of this beach, although not identified throughout any distance, was described by Prof. A. Winchell.* From Lenawee, the Ridgeway Beach extends into Ohio, and becomes identical with the beach of the Maumee Valley, called by Mr. Gilbert number three † Thence it extends eastward with natural interruptions. From Ohio it has been traced into New York by Mr. Gilbert. The portion south of the western half of the lake practically shows no deformation, but between Madison and Sheridan Centre, it rises about a foot per mile, while the lower, or Forest Beach rises in the same distance only about three-quarters of a foot, although eastward of that point the last named beach rises two feet per mile.

At the head of the Maumee valley, a fragment of beach, about 30 feet higher than the Ridgeway Beach, was described in the Geology of Ohio.‡ This, however, is only occasionally met with. A beach at Grand Rapids, Mich., at 700 feet, and a terrace near Allegan at 689, may be the equivalent of that in Ohio.

*The Maumee Beach.*—This is the next highest of the well defined beaches which have been studied. That, at 42 feet above the lake at Chicago, is probably identical with the beach, which has been traced from the southeastern side of the lake, as it is in the topographical position in which we would expect to find it. But the country is very sandy and duny.

The beach is identical with Mr. Gilbert's number one at the head of the Maumee valley, and hence the suitability of the name. When the water was at this level, Mr. Gilbert regarded the outflow of the lake as by the Wabash River. The divide, at the head of this river, from the Maumee drainage was nearly 50 feet below its surface.§ But it was

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*Geology of Washtenaw County, by A. Winchell, 1881.

†Geology of Ohio, map, p. 549 ‡Ibid.

§Geology of Ohio, vol. i., p. 551.

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ame sheet of water had also access
depression at the head of Lake
re below the highest beach in the
he Maumee Beach, east of the
its surface, near Columbia.

*ee Beach, near:*

| | Feet above the sea. |
|---|---|
| t) ................ | 683 |
| .................... | 713 |
| .................... | 841 |
| .................... | 849 |
| .................... | 817 |
| .................... | 784 |
| .................... | 789 |
| .................... | 788 to 778 |
| ....... .......... | 786 |

*Beaches.*—Across the State of
*differential* eastward or north-
han a foot per mile, while that
*lirection*, is a little less than a

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ur. Sci, vol. xli, 1891, p. 15.
. Sci., vol. xi, 1890, p. 447.

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*Higher coast lines.*—There were sheets of water preceding the Maumee episode, for across the higher lands of Michigan there are extensive belts of flat land or plains often covered in part with gravel floors, and in part with silt. They are the exact counterpart of the plains in front of the lower beaches, although more eroded by the streams cutting down to the lower levels. Thus extending from the vicinity of Kalamazoo there is an extensive plain, with a floor of well-rounded gravel, bounded on the south by ridges but with a generally open and descending country to the north. On this plain I have traveled for forty miles to eastward of Marshall, and could see in it no other history than that of the bottom of some bay in front of ridges of drift hills towards the south. The barometric height taken from the station at Kalamazoo gives the plain or terrace an elevation of 912 feet above the sea. Farther east the measurements reached 944 feet. In the valleys, there are lower river terraces probably corresponding to the Maumee Beach. The amount of warping in the region is very little. It has also been noted that there is scarcely any deformation south of Lake Erie until passing eastward of Madison, Ohio. It is well known that there are at least four troughs in Ohio connecting the Erie valley with that of the Ohio River, having summit floors at elevations of between 909 and 940 feet above the sea, composed of drift materials, and that there are terraces at the northern end of these valleys.* The terraces at the head of the Mahoning valley is a good example. It is probable that the gravel plains of Michigan and the terraces in Ohio, connected with these meridional troughs, are identical in age. But here is room for investigation. In Michigan there are other and higher gravel flats than those just referred to.

Professor Rominger records beach-like deposits at 1,682 feet above the sea on the highest lands near the northern part of the lower peninsula of Michigan.† Professor E. Desor noticed other similar deposits at considerable elevations in the northern peninsula of that State.‡ Mr. A. Murray long ago reported a series of beaches on the northern side of Lake Superior.§ Professor H. Y. Hind observed terraces at Great Dog Portage, north of the same lake at 1,435 feet.‖ Other beaches at 1,100 feet have been reported in Wisconsin. None of these have I seen, and do not know which of them, except those north of Superior, belong to true beaches, for I have everywhere had to distin-

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* Geology of Ohio, vol. ii, p. 47.

† Geology of Michigan, vol. iii, p. 10.

‡ See Beaches, etc., between Lakes Mich. and Sup., by E. Desop in Foster and Whitney's Report, vol. ii.

§ Geology of Canada for 1863.

Report upon Assiniboine and Saskatchewan Expedition, 1859, p. 120.

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# CHAPTER VIII.

## Post-Pleistocene Subsidence Versus Glacial Dams.*

(See map, fig. 15, page 75.)

### General Continental Oscillations.

The growing interest in the evolution of the continent now calls for more accurate information than formerly, regarding the changes of level of land and sea in recent geological times. As these oscillations constituted some of the most important factors in the building of the Great Lakes, the study of their history has contributed to our knowledge of the changing relations of the continent and the sea.

From investigation of the submerged channels along the American coast, it has been shown that the continent was greatly elevated during some epoch or epochs intervening between the middle Miocene and the early Pleistocene periods. The elevation of the land was over 3,000 feet higher than now, and probably reached for a short time to over 5,000 feet.†

This elevated condition of the continent was followed by a depression of the land to far below the present altitude before the upward movement produced the now existing condition. There may have been more than one episode of elevation and depression; but the problem that we seek to solve is, *What was the maximum depression of the later Pleistocene times*, after the great beds of boulder clay were formed; for the great elevation was shortly before that period?

Most geologists are ready to accept the high continental elevation, but there are differences of opinion respecting the amount of the subsidence. Although many have their own views upon this subject, few serious attempts have been made to solve the problem uncolored by theory.

### Evidence of Recent Regional Emergence.

We must seek for the evidence of the recent regional submergence in the remains of old shore-lines, such as beaches, terraces and sea-

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*Reprinted from Bull. Geol. Soc. Am., vol. II, pp. 465-476. 1890.

† "The High Continental Elevation preceding the Pleistocene Period," by J. W. Spencer; Bull. Geol. Soc. Am., vol. I, 1889, pp. 65-70.

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Ontario," by J. W. Spencer; Am.

e Huron," by J. W. Spencer; Am.

preclude their formation in confined lakes. Such conditions exist in Ontario, Michigan and Ohio, where extensive surveys have been made. The lower of these shores, as the Ridgeway beach,* like those before named, were formed about bodies of water which opened only toward the north or east. But, ascending a little higher, the Maumee beach† occurs at altitudes which permitted its formation in water having free communication to the Ohio and Mississippi valleys by two depressions. Above this plain there are higher gravel terraces and plains in Michigan and elsewhere, notably those between Kalamazoo and Marshall, with an elevation of a little more than 900 feet above the sea. From them the country falls away by steps toward the lakes; but the sheet of water which they once bounded had at least five connections with the drainage of the Mississippi system. Other higher terraces about more insular points are found in the same region, and farther north, in Michigan, they are said to occur on the summit of the highest land east of Grand Traverse bay, at 1,682 feet above tide.

In Ontario there are well-marked sea-cliffs, carved out of the Niagara escarpment, as westward of Collingwood, especially at elevations of from 1,200 to 1,425 feet above tide. At various intervals between the plain of the Algonquin beach and the highest land of the peninsula (1,709 feet) there are also terrace and beach deposits moulded out of the drift. These remnants of shores are seen to within 20 feet of the highest point of land. The shore markings of these elevated lands are rendered more certain by the perfect water-worn stones, and the extent of the beach and terrace structure. The sea-cliffs are too deeply graven to represent evanescent coast lines. But all of these records are interrupted, owing to the topography of the country, erosion by atmospheric agencies, and the recent Pleistocene deformation of the region.

Some of the positions of the surveyed coast lines are shown in the map, page 75; but for the detailed list of localities reference should be made to a paper on "High level shores in the region of the Great Lakes and their deformation."‡

Again at Dog Lake, north of Lake Superior, Professor H. Y. Hind observed terraces at 1,425 feet above the sea.§

After allowing for all the measurable Pleistocene and recent deformation of the region, these elevated shores stand so high above every natural barrier, even far away toward the south as well as toward the

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* "High Level Shores in the Region of the Great Lakes and their Deformation," by J. W. Spencer, Am. Journ. Sci., vol. xli, 1891, p. 207.

† Ibid., p. 208.

‡ Loc. cit.

§ Assiniboine and Saskatchewan Expedition, 1859, p. 120.

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pt. Z, 1884, p. 143.

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that connecting the trough of Seneca lake with the Susquehanna valley.

Similar elevated terraces have been noted by Professor I. C. White along the upper Potomac valley facing the Atlantic, and along the adjacent tributaries of the Monongahela, which drain to the westward. These deposits he noted up to an elevation of 1,675 feet above the sea, and 175 feet above the valley, along a tributary creek above St. George, West Virginia.*

At Nachvak, in Labrador, Dr. Robert Bell found beaches of great distinctness at 1,500 feet above the sea. Gravel and shingle terraces were also found to an estimated height of 2,000 feet.†

It has already been noted that the differential rise of the Iroquois beach, north of the Adirondack mountains, amounts to seven feet per mile, and that it has there been lifted to a thousand feet. If this rise continues to the White mountains, then the equivalent of the Iroquois beach may be found among the terraces of the high valleys in that region. Its records may be preserved still further northeastward on the drift-covered sides of Mount Katahdin in Maine. Mount Desert, on the coast of Maine, rises to 1,500 feet,‡ and shows remnants of coast action to its summit; consequently it is too low to bear records of the Iroquois shore, unless the warping of the earth's crust becomes one of depression east of the Adirondacks.

In Ontario, some of the high shores, referred to above, occur at elevations of 1,000 feet above the Iroquois plain; therefore, their equivalents in the northern Adirondacks should be looked for at about 2,000 feet above tide. The beaches reported in Vermont by Professor Hitchcock at or below 2,300 feet, doubtless correspond to some high shore-lines of the Ontario peninsula. Upon the same basis these high beaches should be looked for at 3,000 feet in the White mountains, and at greater elevations on Mount Katahdin in Maine.

If we regard the gravels of the highlands of Pennsylvania as having been formed at sea-level, then it would be reasonable to look for their counterparts in New Hampshire, at elevations of over 4,000 feet on Mount Washington and to the summit of the drift (4,400 feet) on Mount Katahdin. These conjectural estimates, based upon a possible uniformity, may aid in the corelation of the topographic features of the mountain region of the east with the lake region.

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* "Rounded Boulders at High Altitudes," by I. C. White: Am. Journ. Sci., vol. xxxiv, 1887, pp. 375-381.

† Rept. Geol. Surv. Can., 1885, DD, p. 8; and Bull. Geol. Soc. Am., vol. 1, 1889, p. 308.

‡ "Geology of Mount Desert," by N. S. Shaler; 9th Ann. Rept. U. S. Geol. Surv., 1888, p. 993.

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‡ On [illegible] he upper Etowah

without containing any marine remains. Even where marine Pleistocene beaches occur on the coast of Norway there are very few localities where shells are found. How many of the older geological formations are unfossiliferous? How many of those ancient beach deposits, now represented by conglomerates, porous sandstones, and indeed many clays, are entirely barren? Under such conditions have we a right to pronounce judgment on the freshness of waters based on the absence of aqueous organic remains? This question will be referred to again in considering the glacial dam theory.

As to the personal equation, it ought not to pass beyond the limit of conservatism, but it is quite proper that it should be considered; for, as Professor Geikie has said, "when controversy ceases the interest in the investigation declines."

## GLACIAL DAMS CONSIDERED.

Glacial lakes are of two kinds: those whose waters are retained by morainic barriers; and others sustained by ice barriers alone.

The former class is represented in several valleys in the Alps, where lateral glaciers enter and cross greater valleys; sometimes the glacier carries its lateral moraine across the valley and builds a more or less permanent earth dam. Such lakes remain long after the glacier has melted away, and even when drained show evidence of their origin. A consideration of this class of glacial lakes does not enter into the subject of this paper.

In Switzerland, Greenland and Alaska other glacial dams are now well known. These are retained by the ice alone. When glaciers, free from morainic materials, descend lateral valleys and across other valleys, they do not obstruct the rivers, for they continue to flow beneath the ice. However, there are many places where glacial lakes occur between the ice and the sides of the valleys; especially is this the case where two glaciers meet at the end of a mountain spur, like Lac Tacul in Switzerland. Small glacial lakes, like the Marjelen-see, sometimes occur where lateral valleys unite with the glacier-filled channels. All modern glacial lakes are of small size. One of the largest lakes described in Greenland is not over three or four miles long and a mile wide. Such lakes, when they exist above sea level, are evanscent. Mr. H. Topham described some glacial lakes of Alaska which discharge by a tunnel, eight miles long, under 500 feet of ice. Mr. I. C. Russell makes similar reports. The outflowing waters enlarge the tunnels, thereby draining the lakes; but the ice roofs fall in, and by the accumulation of ice blocks the tunnel becomes temporarily

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Spencer; Quart. Journ.

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cut terraces and beaches, requiring centuries or millenniums of time, could scarcely have been formed except at sea-level.

If the Algonquin beach of the upper lakes were formed in a glacial lake, then the ice barrier in the region of Lake Nipissing would have reached 600 or 700 feet beneath the surface of the water. The drainage must have been under the ice, and have amounted to a discharge equal to that of the modern Detroit river, as the discharge of Lake Superior, Lake Michigan and Lake Huron basins would have been thus borne seaward, descending 300 feet to the level of the Iroquois water. Under such conditions, the question may be asked, How could the lake surface be retained long enough at any level to carve out the deeply graven water lines and terrace plains of the Algonquin beach, in place of the discharging waters melting away the icy barriers, which were supposed to have been the means of retaining the lake 300 feet above the level of the Iroquois waters?

We now rise to the shores which bounded the Warren water. These I have explored from Lake Michigan to New York, and to the eastern portion of the Ontario peninsula. Under the glacial-dam theory, this sheet of water would need a barrier to the north as well as to the east. The drainage of the lake, at all stages, from the Ridgeway beach downward, was to the northeast, and beneath a greater hypothetical mass of ice than in the case of the Algonquin or Iroquois waters; but above the Ridgeway beach,* at the Maumee level,† there were outlets across Ohio and Illinois, if a lake it were. The difficulties are increasing.

The shore-markings occurring at Kalamazoo, at about 900 feet above tide, represent a sheet of water having at least five outlets across Ohio and Illinois. Again, the sea-cliffs of the Ontario peninsula, at from 1,200 to 1,425 feet and more, and the beaches now found up to 1,689 feet, would demand great dams toward the south and west as well as toward the north. But such dams could scarcely have existed with open waters carving out sea-cliffs and terraces on the high peninsula of Ontario, and also leaving records 200 miles southward. It should be noted that gravel deposits of the so-called kame and osar structures occur at all high levels; but of these I do not take cognizance.

The drainage of the high country, such as the Genesee valley, with terraces up to 1,900 feet or more, and of the "terminal moraine," up to 2,680 feet, was toward the north without obstruction.

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* "High Level Shores in the Region of the Great Lakes and their Deformation," by J. W. Spencer: Am. Journ. Sci., vol. xli, 1891, p. 267.

† Ibid., p. 268.

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DURATION OF NIAGARA FALLS.

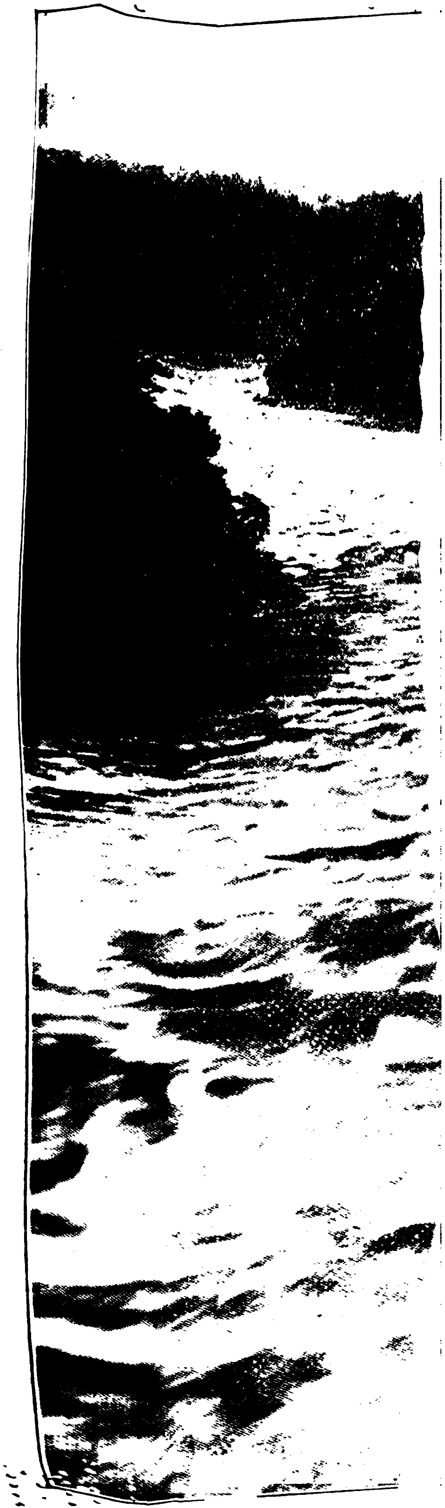

PLATE V.

the channel to become broader — a principle which has an important bearing in this study. While the observations are imperfect, owing to the variable conditions of erosion, still the attempt to ascertain the duration of the different episodes is the only natural sequence to the measurements of the modern recession of the falls, and it gives approximate results, for without considering the changing episodes the rate of recession is of no geological interest. But this study may lead to further detailed investigations.

## *Episodes of the River and the Duration of each — Age of the Falls.*

*First Episode.*— From the history of the lakes and the river we learn that the early falls cascaded from the brow of the escarpment to the level of the Iroquois beach 200 feet below, (with the Erie drainage only $\frac{3}{11}$ of the total discharge of the upper lakes). There is no indication that the Erie rainfall was greater at that time than now. The length of the chasm excavated during the first episode is found in the data furnished by the study of Foster's flats. Their location is shown at F, figure 17, and the structures are further illustrated in figures 21 and 22.

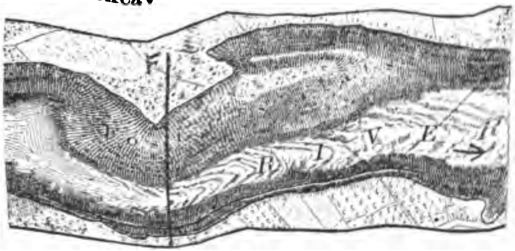

FIG. 21.—Map of the gorge at Foster's flats; F, location of the cross section fig. 20.

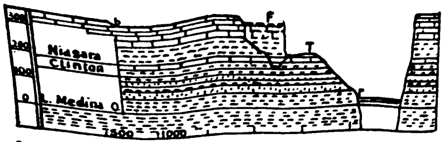

FIG. 22 — Section of the gorge at Foster's flats (FT, fig. 17). Platform (F) of the old river floor projecting into the cañon. Its section is shown in broken shading but with ravines descending from both sides of it. T, rock terrace surmounted by huge blocks of Niagara limestones; *b*, original river terrace; *r*, surface of river; L. O., surface of Lake Ontario. Bottom of river about 80 feet below the surface of the lake.

The terrace (T) represents the former level of the river (about 190 feet above Lake Ontario). It is the only feature of the kind in the cañon. It is about 50-60 feet above the Iroquois level to which the

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*Second Episode*
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upper cascade receded by itself past Foster's terrace, a distance of 3,000 feet. Thus closed the first stage of the second episode. After passing Foster's flats the chasm shows the effects of a greatly increased force, for the gorge is again widened with the terrace below washed away. As no change in the total height occurred about this time, the magnitude of the erosion indicates an increased discharge, which was produced by the turning of the waters of the Huron basin and adding them to the Niagara drainage. The effects of the greatly increased volume of the water were to widen the chasm and cut away part of Foster's platform, but leaving enough to tell the history. The upper falls were not joined by the more rapidly retreating lower cascades until after the whirlpool was passed, for the evidence of the upper water-level is left in the deposits of river gravels at an elevation of 190 feet on the northern side of the whirlpool ravine, which would not have been the case if the river were at a lower level after cascading over one united falls. Just above the whirlpool, the chasm becomes narrow, and here I close the second stage of this episode of three cascades. The length of this section of the gorge from (C to D fig. 24) is 7,000 feet. By considering the proportional amount of work accomplished during the elongation of the chasm, the deepening of the gorge left at the close of the first episode, and its extension 12 miles lakeward (the mean depth of shales removed from eight miles was 180 feet, and from

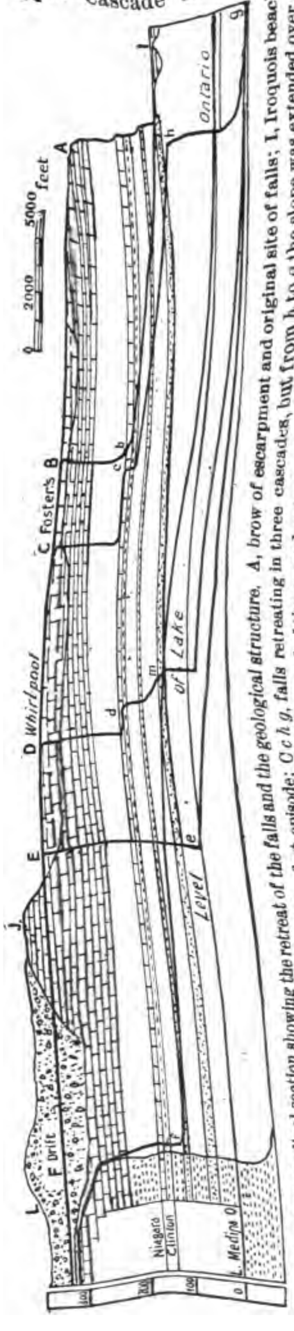

FIG. 24.—Longitudinal section showing the retreat of the falls and the geological structure. A, brow of escarpment and original site of falls; I, Iroquois beach and level of that water; B b I, chasm at the end of the first episode; C c h g, falls retreating in three cascades, but from h to g the slope was extended over a distance of 12 miles beyond the escarpment; D d m g, position of cataracts at the end of the second episode; E e g, development of gorge at the end of the third episode; e', present site of falls, and F m g, the modern cañon; g, level of the lowest stage of water in the river history; L, Lundy beach capping the drift; J, Johnson's ridge. Broken shading about whirlpool shows occurrence of drift on west bank only with rock on the eastern; block shading represents limestone; dotted, sandstone; broken lines and unshaded portion, shales. Bottom of river 80 feet below present surface of Lake Ontario, as shown in figure.

four miles, 60 feet), and applying
the first stage required 6,000 y
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*Third Episode.*—The narrowe
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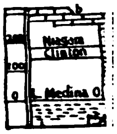

FIG. 25.—Section across the narrows just
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*Fourth Episode.*—This is
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at the head of the whirlpool rapids, a phenomena explained by the force of the river being vertically diminished and latterly increased—the converse to the conditions of those of the third episode. At first the rocks in Johnson's ridge offered great resistance on account of the increased thickness of limestones nevertheless the lateral erosion gained the ascendancy over the vertical. The section through Johnson's ridge is 5,500 feet long, and with the laws of erosion the time necessary for the falls to retreat through it would be about 1,500 years—thus would end the first stage of the last episode. The last stage is the modern, or that since the cataract reached the Tonawanda basin south of Johnson's ridge, whose rocky floor, generally speaking, is about 80–90 feet lower than that on the ridge (see fig. 24); yet the cañon just north of the ridge is only 250 feet wider than through that barrier. The drift filling the basin offered but little resistance to the recession of the falls and accordingly the rate of retreat has been comparatively rapid along this section of the river, which is 6,000 feet long. Consequently its age is about 1,500 years. Thus the duration of the fourth epoch has been 3,000 years.

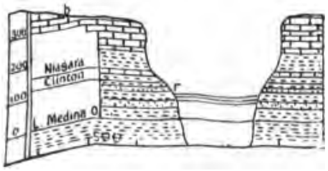

FIG. 26.—Section across the gorge at Johnson's ridge (*ee*, fig. 17); L. O. level of Lake Ontario; *r*, surface of river; *b*, original bank of river; bottom of river 80 feet below surface of the lake

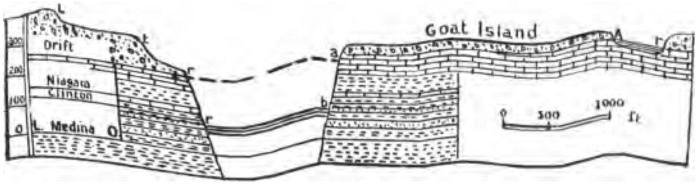

FIG. 27.—Section across gorge 1,000 feet north of the Horseshoe falls (*cc*, fig. 17) L, Lundy beach to the west; *t*, terrace with sandy face; *ra*, surface of river at crest of falls; *rs*, ditto below falls; *Ar*, ditto of American falls; L. O., level of Lake Ontario. Bottom 80 feet below lake surface.

*Age of Falls.*—Allowing 1,000 years for the duration of the river before the advent of the falls,—for that its commencement was not characterized by a cascade is shown by the terraces on

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* Elevation south of and adjacent to

† The waters of both Lundy and A
beginning of the *Niagara river; this*
uplift of about half a foot per mile, th

the birth of Niagara Falls. Of this latter amount about 130 feet have been lifted since the waters were turned into the Niagara drainage. Again we get some proportions.

The ratios of the deformation of the Lundy and Iroquois beaches are about the same, and we have the Lundy beach differentially raised 160 feet in the Niagara district, and the Iroquois beach deformed to 370 feet near the outlet of Lake Ontario (compared with the level at the head of the lake) since the close of the Iroquois episode. And here there are data for comparison. These figures have been mostly taken from the papers already cited. Compiling the results derived from all these data, it appears that:

A. The time which has elapsed since the Iroquois episode, or the end of the first episode of the falls, is:

| | | Years. |
|---|---|---|
| A. | (1) From the computation given | 13,800 |
| | (2) From the date of deformation recorded in the Iroquois beach* | 14,800 |
| | (3) From the deformation recorded in the Lundy beach†, | 12,800 |
| | Mean result | 13,800 |
| B. | (1) Computed time since the Huron waters turned into the Niagara | 7,800 |
| | (2) From the proportional deformation of the Algonquin (N. E.) outlet compared with the computed age of the river‡ | 7,400 |
| | (3) From the proportional deformation of the Algonquin uplift§ | 6,500 |
| | Mean result | 7,233 |
| C. | (1) Computed age of Niagara river | 32,000 |
| | (2) From the rate of deformation of Algonquin beach since the commencement of Niagara river‖ | 28,000 |
| | Mean result | 30,000 |

These computations were originally made not to seek for favorable evidence but to discover discrepancies, for I did not expect that the data had been correlated with sufficient accuracy; but the several

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* A differential rise of 370 feet at the outlet of Lake Ontario divided by 2.5 feet a century.

† A rise of 160 feet in the Niagara district divided by 1.25 feet a century.

‡ One hundred and thirty — five-hundred-sixtieths of 32,000 years.

§ Thirteen fifty-sixths of 28,000 (see next note)

‖ Rise of 660 feet in the Algonquin beach less 100 feet before the birth of the Niagara at the rate of 2 feet a century.

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[*] The beaches show an elevation a
[illegible] to 30 feet above [illegible] of
Niagara river.

through the Johnson ridge was effected. With the present rate of calculated terrestrial uplift in the Niagara district, and the rate of recession of the falls continued, or even doubled, before the cataract shall have reached the Devonian escarpment at Buffalo, that limestone barrier shall have been raised so high as to turn the waters of the upper lakes into the Mississippi drainage by way of Chicago. An elevation of 60 feet at the outlet of Lake Erie would bring the rocky floor of the channel as high as the Chicago divide, and an elevation of 70 feet would completely divert the drainage. This would require 5,000 or 6,000 years at the estimated rate of terrestrial elevation. It would be a repetition of the phenomena of the turning of the drainage of the upper lakes from the Ottawa valley into the Erie basin.

### *Conclusions.*

The computation of the age of the Niagara river,—based upon the measured rate of recession during 48 years; upon the changing descent of the river from 200 to 420 feet and back to 320 feet; and upon the variable discharge of water from that of the Erie basin only, during three-fourths of the life of the river, to afterwards that of all the upper lakes,—leads to the conclusion that the Niagara Falls are 31,000 years old and the river of 32,000 years duration; also that the Huron drainage turned from the Ottawa river into Lake Erie less than 8,000 years ago. Lastly, if the rate of terrestrial deformation continues as it appears to have done, then in about 5,000 years the life of Niagara Falls will cease, by the turning of the waters into the Mississippi. These computations are confirmed by the rate and amount of differential elevation recorded in the deserted beaches. It is further roughly estimated that the lake epoch commenced 50,000 or 60,000 years ago, and there was open water long before the birth of Niagara in even the Ontario basin, and that under no circumstances could there have been any hydrostatic obstruction to the Ontario basin since before the birth of Niagara Falls.

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" " " confirmed ... 114
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